REMARKS

Status of the claims

Claims 15-52 were pending and under active consideration in the subject application. With this submission, claims 15, 23, 33, 41 and 51 have been amended; and claims 21, 22, 39, and 40 have been canceled. No new claims, however, have been added. Hence, upon entry of this paper, claims 15-20, 23-38, and 41-52 will remain pending and under active consideration.

Applicants respectfully request reconsideration of the present application in view of the foregoing amendments and in view of the reasons that follow.

Statement of the substance of an Interview

Undersigned counsel for Applicants wishes to sincerely thank Examiners Buie and Zimmer for extending the courtesy of an interview held at the USPTO on 30 June 2009. As noted in the Interview Summary of even date, the unexpected synergy (discussed herein) between rapeseed methylmonoester ("RME") and ethylene bis-stearamide ("EBS") in increasing the Ring & Ball softening point of bituminous binder compositions comprising same was discussed. While no agreement was reached, the Examiners appeared to agree that claims tailored to the unexpected showing would be favorably considered.

Claim rejections under 35 U.S.C. § 103

Claims 15-22 stand rejected under 35 U.S.C. § 103(a) as being allegedly unpatentable over DE 19519539 A1 to Hackl *et al.* ("Hackl") in view of WO 00/73378 A1 to Dempsey *et al.* ("Dempsey"). The Examiner alleges that Hackl discloses a binder composition comprising 50-99 wt. % bitumen, elastomer, and 2-25 wt. % to a mono-alkyl ester of a vegetable oil. Office Action at page 2. Because Hackl is silent on "an amide additive," the Examiner has combined the teachings of Dempsey, alleging that one of ordinary skill in the art would have been "obviously" motivated to combine EBS with the compositions of Hackl because Dempsey suggests that EBS can "significantly lower viscosities at process and handling temperatures." *Id.* at page 3. In other words, the Examiner alleges that it would

have been obvious to combine the teachings of Hackl and Dempsey and obtain the *expected* benefits of EBS in a composition comprising same.

Even if it were assumed, *arguendo*, that Hackl could properly be combined with Dempsey, the fact would remain that neither reference would have lent credence to an expectation by the skilled artisan of achieving the superior results documented with the presently recited combination of RME and EBS. As will be next discussed, the magnitude of the results obtained by the claimed invention would certainly have surprised the skilled artisan, as the synergistic cooperation of EBS with RME in increasing the Ring & Ball softening point[1] of bituminous binder compositions was heretofore unknown to the ordinary artisan. Hence, Applicants respectfully traverse the present rejection on the ground that the claimed invention possesses properties that the skilled artisan would have deemed surprising at the time the invention was made.

Pursuant to the present invention,[2] as described in Examples 1 and 2, compositions comprising bitumen, polybutadiene (*i.e.*, "an elastomer"), RME, and 0.75% or 1.75% EBS, respectively, were prepared.[3] By way of comparison, an identical mixture was prepared, provided that no EBS was added. *See* Comparative Example 1. The Ring & Ball softening point of these samples was determined after 24 hours according to ASTM D-36 protocol. The results of these measurements, presented graphically in Figure 2, evidence that the softening point of the inventive bituminous binder compositions can be increased about 12 °C per wt. % of EBS added. Applicants respectfully submit that none of the cited art could have predicted such an effect.

---

[1] Should it concern the Examiner, bituminous binder composition having relatively high softening points are desirable at least because such compositions have improved processability under road construction conditions and because the resultant product is harder at higher ambient temperatures, which curbs, e.g., "blackening up" of the asphalt layer. *See, e.g.*, Background of the Invention and the paragraph before Example 1.

[2] An Applicant is entitled to submit evidence of unexpected results in the specification as originally filed. MPEP § 2142. Should the examiner request, however, the noted evidence from the specification can be submitted in the form of a Rule 132 Declaration.

[3] To be sure, the compositions disclosed in Examples 1, 2 and Comparative Example 1 further comprise a "curing agent" and an "aminofunctional adhesion promoter." Applicants respectfully submit that these optional components merely aid (*e.g.*, expedite) the application of the bituminous binder compositions (*e.g.*, in

To the contrary, at best, the prior art would have suggested an increase in softening point of only about 4-6 °C per wt. % of EBS, still less than half of what was discovered by the present inventors. For example, Dempsey teaches compositions comprising asphalt (*i.e.*, "bitumen"), Elvaloy® AM polymer (*i.e.*, "an elastomer"), and an amide. Example 7, Table II. These compositions, which lack RME, exhibit only about a 5 °C increase[4] in softening point per weight of amide added. Similarly, as noted in the present application, Table 1 of WO 03/062315 discloses that the addition of 1 wt. % of EBS to bituminous compositions *lacking RME* increases the Ring & Ball softening point just 4 °C.

During the Interview, the Examiners did not appear to question the "unpredictability" of these results. Rather, the Examiners advised that the claim language should be commensurate in scope with the evidence presented. In a good-faith effort to advance prosecution of the present case, therefore, Applicants have amended the claims to specify RME as the "mono-alkyl ester of a vegetable oil or an animal oil" and EBS as the "amide additive". Applicants respectfully submit that the present claims capture the unexpected phenomenology underscored in the aforementioned Examples and in Figure 2 and, hence, are commensurate in scope with the evidence of unexpected results. Accordingly, withdrawal of the subject obviousness rejection is respectfully requested.

The remaining claims stand rejected under 35 U.S.C. § 103(a) as being allegedly unpatentable over Hackl in view of Dempsey, and further in view of USP No. 4,129,542 to Matheson *et al.*, USP No. 6,444,731 to Memon, and/or U.S. publication no. 2004/0033308 to Barthel *et al.* Applicants respectfully traverse these rejections.

Even if it is assumed, *arguendo*, that Matheson, Memon and/or Barthel is properly combinable with Hackl and Dempsey, the fact remains that neither reference would have

---

road construction), and that these components do not materially affect the physical properties *per se* of the binder compositions.

[4] To be clear, Dempsey actually provides the "performance grade" ("PG") classification of the compositions tested. Because both PG and Ring & Ball (RB) softening points measure rheological properties of a given composition, they have a linear relationship with a correlation coefficient R2=0.98, which can be described by the following equation: PG = 1.17*(RB) + 8.7. See page 6 of Green, et al., The classification of bitumens and polymer modified bitumens within the SHRP performance grading system (attached herewith). Hence PG70 and PG76 correspond to a RB softening point of 68.5 °C and 73.7 °C, respectively—a difference of about 5 °C.

prompted a contemporaneous expectation of the superior results documented by present inventors' claimed combination of RME and EBS. Applicants submit that the above-discussed showing of unexpected results, likewise are effective against the combination of Hackl, Dempsey and other secondary references. In the interest of brevity, the evidence proferred hereinabove is not repeated here.

Applicants respectfully maintain that the claimed invention possesses improved properties that, in view of the cited, could not have been expected by one of ordinary skill in the art at the time the invention was made. Applicants therefore solicit withdrawal of the rejections under 35 USC § 103(a).

Conclusion

Applicants believe that the present application remains in condition for allowance. Favorable reconsideration of the application as amended is respectfully requested. The Examiner is invited to contact the undersigned by telephone if it is felt that a telephone interview would advance the prosecution of the present application.

The Commissioner is hereby authorized to charge any additional fees which may be required regarding this application under 37 C.F.R. §§ 1.16-1.17, or credit any overpayment, to Deposit Account No. 19-0741. Should no proper payment be enclosed herewith, as by a check or credit card payment form being in the wrong amount, unsigned, post-dated, otherwise improper or informal or even entirely missing, the Commissioner is authorized to charge the unpaid amount to Deposit Account No. 19-0741. If any extensions of time are needed for timely acceptance of papers submitted herewith, Applicants hereby petition for such extension under 37 C.F.R. §1.136 and authorizes payment of any such extensions fees to Deposit Account No. 19-0741.

Respectfully submitted,

Date July 13, 2009 (Monday)

By S. Talapatra

FOLEY & LARDNER LLP
Customer Number: 22428
Telephone: (202) 295-4621
Facsimile: (202) 672-5399

Gilberto M. Villacorta, Ph.D.
Registration No. 34,038
Sunit Talapatra, Ph.D.
Registration No. 54,482

The Classification of Bitumens and Polymer Modified Bitumens Within the SHRP Performance Grading System

by M J Claxton and P J Green
BP Oil International

Introduction

Currently, in most countries around the world, bitumens are graded according to a number of traditional, and often empirical, tests. For example, in the UK, penetration and softening point have long been the basis of the grading systems. Elsewhere, fundamental properties such as viscosity have also been specified. Historically these specifications have provided a reliable means of classifying binders and are familiar to authorities, specifiers, binder suppliers and road contractors. Based on these properties, binder suppliers have built up experience of how different binders will comply with these specifications. This has included developing the expertise to manufacture good quality bitumens from a diversity of crude oils.

In 1997, a very different binder grading system was introduced in the USA. This was one of the principal outputs from the Strategic Highway Research Program (SHRP) and is based on a number of fundamental, rheological properties of the binder. Within this system, rather than a binder being classified by for example penetration at 25°C (e.g. 70 or 100 pen), it is classified by two numbers e.g. "64-28", "58-22" etc. The first of these numbers is an indication of the binder's high temperature performance and the second relates to its low temperature performance. This performance grade (the PG grade) may be thought of as a type of 'plasticity' range for the binder. Such a fundamental grading system should have the benefit of being applicable to both unmodified bitumens and speciality products such as Polymer Modified Bitumens (PMBs). However, it is clearly not a classification with which the bitumen and asphalt industry is familiar. Similarly, it is too early for experience to have been developed on how to manufacture bitumens which meet specified SHRP grades.

This paper describes work in which SHRP grades have been determined for a number of bitumens (covering a wide range of grades and produced from a variety of crude oils by different manufacturing routes) to see how they fit into this grading system. It also describes how the benefits of PMBs can be quantified within the system. Finally, for unmodified bitumens a comparison is made between traditional, empirical properties and the new SHRP grades to determine whether there are relationships between the two systems.

Traditional binder specification

Traditional binder specifications tend to be based either on empirical measurements, for example penetration, softening point, or on rheological measurements at fixed, high temperatures for example viscosity at 60 and 135°C.

FIGURE 1 Penetration versus softening point for CEN specifications

Such specifications may be displayed graphically. Figure 1 shows a plot of penetration versus Ring and Ball softening point and includes the grade ranges for conventional paving grade bitumens from the proposed European CEN specifications. It is the aim of the binder supplier to produce bitumens whose properties fall within the specifications box for each grade. Binders which fall outside, to the left of these grading boxes (i.e. have low softening points for a given penetration) tend to be poor quality bitumens of high temperature susceptibility.

The SHRP binder sepecifications

The SHRP binder specifications have been developed specifically for bitumen for use in dense mix wearing courses and, being fundamental in nature, shoul be applicable to unmodified and modified binders (e.g. (1)). A portion of the SHRP binder grading chart is shown in Table 1.

Performance Grade	PG 58-			
	16	22	28	34
Average 7-day Maximum Pavement Design Temp°C	<58			
Minimum Pavement Design Temperature °C	>-16	>-22	>-28	>-34
Original Binder				
Flash Point Temp, T48: Minimum °C	230			
Viscosity, ASTM D 4402:Maximum, 3Pa.s, Test Temp °C	135			
Dynamic Shear TP5: G*/sind, Minimum 1.00 kPaTest Temperature @ 10 rad/sec, °C	58			
Rolling Thin Film Oven Residue (T240)				
Mass Loss, Max., %	1.00			
Dynamic Shear TP5: G*/sind, Minimum 2.20 kPaTest Temperature @ 10 rad/sec, °C	58			
Pressure Aging Vessel Residue (PP1)				
Physical Hardening	Report			
Creep Stiffness, TP1:S, Maximum, 300 MPam-value, Minimum, 0.300Test Temp@ 60s, °C	-6	-12	-18	-24
Direct Tension, TP3:Failure strain, Min., 1.0%Test Temp @ 1.0mm/min, °C	-6	-12	-18	-24

Table 1 extract from SHRP binder grading system

These specifications have been designed to address the three main failure mechanisms for asphaltic concrete, the most commonly used dense mix in the USA. As shown these are:

- Permanent deformation (rutting) at high service temperatures
- Fatigue at intermediate service temperatures
- Brittle fracture at low service temperatures
- The specifications also include a pumping and handling requirement (viscosity at 135°C) and a flash point specification. Both fatigue failure and brittle fracture at low temperatures tend to occur in older pavements. Therefore the specification includes measurements on
- 58°C is the maximum 'design' road temperature. G*/sind at 10rad/s (measured using a Dynamic Shear Rheometer) must have a minimum value of 1kPa unaged and 2.2kPa after RTFOT. To perform well in terms of resisting rutting, a binder should either be stiff (high G*), or
- -16°C is the minimum road temperature. At -6°C (10°C is added to speed up laboratory testing), the binder must have a maximum stiffness of 300MPa and a minimum m-value of 0.3 after RTFOT and PAV. Both are measured using the Bending Beam Rheometer (BBR).

Binders which fulfil both criteria will be less stiff and better able to relax thermal stress build-up at low temperatures. (If the binder has a stiffness in the range 300-600MPa but passes the m-value criterion, it may be further tested using the Direct Tension Tester.)

Further DSR measurements are required to calculate the fatigue parameter (G*sind at 10 rad/s) at an intermediate temperature. For the PG 58-16 grade, it is measured at 25°C (Table 1). A maximum value is specified i.e. SHRP proposes that the use of more compliant, elastic binders helps to address the problem of fatigue cracking.

In summary, the main difference between traditional specifications and SHRP specifications is:

These specifications have been designed to address the three main failure mechanisms for asphaltic concrete, the most commonly used dense mix in the USA. As shown these are:

- Traditional specifications conduct a test under fixed conditions regardless of grade. A measured parameter must have a certain value to meet a grade, e.g. a 50 pen binder must have a penetration of 50±10 mm/10 at 25°C.
- SHRP specifications conduct a test under conditions (temperature) determined by the grade. A measured parameter must meet a fixed value regardless of grade, e.g. to meet the PG 64- grade G*/sind must be a minimum of 1kPa (unaged) at 64°C.

The benefits of performance-based specifications

Traditional specifications were developed on the basis of experience with unmodified binders. However, with the advent of heavier axle loads and increasing traffic densities the use of PMBs and other speciality binders is increasing. A consequence is that, whilst empirical properties have been used as an indicator of performance, such relationships may not always be valid for modified binders. Work by BP (2) showed that, whilst softening point is a good indicator of rut resistance for most binders, there are outliers which have high softening points but do not perform as expected when tested in asphalt. The parameter recommended by SHRP was found to be a much more reliable predictor of rutting performance for many binders, including PMBs.

At low temperatures, the fraass breaking point has been found to correlate with mix fracture temperature. Drawbacks of such a measurement however, include relatively poor repeatability and reproducibility for the manual and automatic test methods. Difficulty in detecting cracking in the binder film has been reported for some PMBs. Work reported in (3,4) shows good repeatability and reproducibility obtained by two different laboratories with the BBR and a good correlation between BBR data and mix fracture temperature. The SHRP fatigue parameter was also investigated (2). This confirmed a broad trend that the lower the value of G*sind the better the fatigue life of the mix. However, this parameter was not as good as those specified at high and low temperatures for discriminating between the mix performance for different binders.

On the basis of some of this work, it appears that binder rheological measures, for example those included in the SHRP specifications, may be used as indicators of mix performance. They have the advantage that they appear to work equally well for unmodified binders and speciality products and may be used to compare binders for a given mix.

Materials and test methods

In order to compare the SHRP grading system with more familiar parameters a large set of binders were fully characterised rheologically. 25 binders were tested in total, 10 unmodified, paving grade bitumens and 15 speciality binders including PMBs.

Binders characterised

Paving grade bitumens were selected to cover a range of grades (15-200 pen) and were manufactured from various crude oils using different production routes. PMBs were based on a number of different base bitumens and included different polymer types (elastomeric and plastomeric) and concentrations, to cover a range of rheological characteristics. Speciality products which were not PMBs were also included.

Test methods

All binders were characterised (unaged) using standard empirical test methods such as penetration (IP 49) and softening point (IP 58). Further details on the rheological tests are given below.

Dynamic shear rheometer

Testing with a dynamic shear rheometer (DSR) was carried out on the binder unaged, after RTFOT (AS2341.10) and after both RTFOT and PAV (100°C). Parallel plate test geometries appropriate for the range of stiffness measured were selected. Measurements were made over a range of temperatures at 1.6 Hz. The specified SHRP parameters were plotted as a function of temperature and the temperature at which the critical values occurred were determined. For example, for the criterion to control rutting, G*/sind at 1.6 Hz was plotted as a function of temperature and the temperature for which it had a value of 1kPa (unaged) was determined.

Bending beam rheometer

BBR testing was carried out on all binders after ageing in both the RTFOT and the PAV. As for the DSR testing, measurements were made over a range of temperatures (at a loading time of 60s). The stiffness and the m-value were both plotted as a function of temperature and the temperatures at which the critical values occurred were determined.

Determination of SHRP grades

Although full sets of data for the binders are not included in this paper, the method used to determine the SHRP grade of a 100 pen binder is given as an example:

1. The temperature at which G*/sind1.6Hz = 1kPa (unaged) is 60.0°C. After RTFOT G*/sind1.6Hz = 2.2kPa at 59.8°C. The high temperature grade in both cases is PG 58 (Table 1). The rest of the grade is determined from this column of the grading chart.
2. After RTFOT and PAV, the temperature at which S(60sec)=300MPa is -19.7°C. The temperature at which the m-value=0.3 is -23.3°C. Both criteria are fulfilled at -18°C. From the top of the chart, this equates to a low temperature grade of PG -28.
3. After RTFOT and PAV, G*.sind1.6Hz = 5000kPa at 18.0°C. From the fatigue criterion row in Table 1, this confirms the lower temperature grade of PG -28.

The final SHRP grade determined for the 100 pen binder would therefore be a PG 58-28. Using this method, SHRP grades for all binders were determined.

Defining Critical Temperatures and A Grading Chart

In addition to determining the SHRP grades for the binders, the above analysis also enables a pair of critical values to be determined. For the 100 pen binder used in the example above, a "high temperature critical value" is defined as the lower temperature determined (i.e. worst case) for the two criteria relate to rutting resistance (G*/sind^{3}1kPa before RTFOT and G*/sind^{3}2.2kPa after RTFOT). In this example this would be 59.8°C. Likewise the "low temperature critical value" is the higher (i.e. worse) of the two temperatures determined from BBR data, in this case (-19.7 - 10 = -29.7)°C.

Defining these parameters for each binder enables the SHRP grades to be displayed graphically in a similar way to the penetration/softening point specifications. Figure 2 shows a blank Grading Chart with high and low temperature critical values on the x and y axes respectively.

Each axis is divided into 6°C increments which correspond to the SHRP binder grades. For example any binder within the box highlighted would be classified as a PG 64-22. Moving in the direction of the arrow corresponds to improved performance at high and low temperatures. The further towards the bottom right hand corner a binder is, the better its performance would be anticipated to be according to the SHRP binder grading system.

Figure 2 Grading Chart for Displaying SHRP Critical Values

Results

Unmodified binders

Figure 3 shows all the unmodified binders plotted on the Grading Chart. As would be expected, the lower penetration (harder) products are all classified within the higher SHRP high temperature grades, corresponding to good resistance to permanent deformation.

Figure 3 grading chart for BP unmodified binders

The 10/20 pen binders are all in the PG 82- grade, and the low temperature performances are at the worse end of the range. Better low temperature performance would not be expected for an unmodified binder. The 40/50 pen grade binders are classified as PG 70-22: two high temperature grades lower than the 10/20 pen binders and have slightly better low temperature performance. The 60/70 grade binders and the 100 and 200 pen are classified as PG 64-, 58- and 52 respectively, with improving low temperature grades for the softer binders as would be expected. In terms of the standard set of SHRP high temperature grades (PG 46 - PG 82), the unmodified binders included in this study cover most of them - a 300 pen bitumen would probably be classified as a PG 46. So PG 46- to PG 82- corresponds approximately to a penetration range of 15-300 mm/10.

Figure 3 also highlights differences within the grades. For example, the 200 pen bitumen nominally has the same low temperature grade as the 100 pen bitumen (Table 1) but it is borderline PG 52-34. Figure 3 also shows that a greater range of SHRP high temperature grades (7) are covered than low temperature grades (5). There is more differentiation between the bitumens by the high temperature grades.

It is also clear that these conventional, good quality, unmodified binders fall on a straight line, even though they were produced from different crudes using different production routes. The correlation coefficient for the straight line fitted to the data is high, R2=0.98 and the low temperature critical value for unmodified binders can be predicted as follows:

- low temp critical value = 0.51*(high temp critical value) - 60.7

These data suggest that, for unmodified binders, DSR measurements before and after RTFOT to determine the high temperature SHRP grading should be sufficient to also predict the low temperature grade of the binder (equation 1). For all binders tested in this work, the SHRP fatigue criterion did not adjust the grade: the low temperature grade was always controlled by the BBR critical temperatures. Therefore the high temperature critical value and equation (1) enable the complete SHRP grade to be determined.

Figure 3 also suggests that a limited number of SHRP grades can be met by conventional, unmodified binders. These are: PG 82-16; PG 76-16; PG 70-22; PG 64-22; PG 58-28 and PG 52-28. The line also just passes through the PG 76-22 and PG 64-28 grades, but these would not be expected to be met very often and are borderline grades for conventional bitumens. Although the binders are on a line, any grade to the upper left of the line would also be met by conventional bitumens. For example, a PG 64-22 binder meets all high temperature grades up to 64 and all low temperature grades down to -22. A requirement for a binder to meet the PG 58-16 grade would be fulfilled by a 100 pen binder, a 50 pen binder etc. It is intuitively reasonable to believe that the SHRP grades to the upper left of the line could also be met by inferior binders of high temperature susceptibility (similar to those to the left of the boxes in Figure 1). Binders adversely affected by ageing may also be in these grades.

SHRP grades below the line have improved low or high temperature performance or a combination of both. To meet these grades, a speciality binder is required.

Speciality binders

All speciality products and PMBs were classified according to the SHRP grading system.

Figure 4 shows an equivalent plot to figure 3 including all the modified binders together with the straight line fitted to the unmodified binders. For this data set, all the speciality binders are below the line for the unmodified binders. The best performing product in Figure 4 is classified as a PG 82-34. Comparison with gradings for the unmodified binders confirms that this product would have equivalent high temperature performance to a 10/20 grade unmodified binder combined with the low temperature (and fatigue) performance similar to that of a 200 pen binder. It should also be noted that, for both critical temperatures, data include the effect of ageing in the RTFOT and for low temperature performance also the PAV. Therefore the PMBs and speciality binders have performance benefits compared with unmodified bitumens after these ageing processes.

To quantify the effect of polymer modification on the SHRP grade, it is also interesting to consider a single polymer system only. The data plotted in Figure 5 were extracted from (5), for inclusion in the current study. Three different grades of bitumen (A45 (35/50), A65 (50/70) and A85 (70/100)) were each modified with the same amount of SBS polymer and the A65 grade was further modified by the addition of more SBS polymer. Data for other unmodified binders in (5) were also plotted.

Figure 4 grading chart for BP unmodified and modified binder

Figure 5 grading chart for unmodified and SBS modified binders (data from (5))

Figure 5 confirms that these 8 additional unmodified binders are on the straight line applied to the original data set. The addition of SBS polymer to each base bitumen increases the SHRP high temperature grade by one: all the points have shifted towards the right indicating improved high temperature performance. This high temperature shift increases as the penetration of the binder increases i.e. it is greatest for the A85 grade binder. The opposite is true for the low temperature grade. In this case the hardest base bitumen has the greatest improvement in low temperature performance, with the largest downward shift. Only the A85 bitumen has an improved SHRP low temperature grade, due to its original position. Further increasing the SBS polymer content for the A65 base bitumen gives almost double the benefit in terms of temperature shifts (both high and low), increasing the SHRP grading from PG 64-22 for the base bitumen to PG 76-28.

In general, modifying different base bitumens with the same concentration of the same polymer gives different degrees of enhancement in low and high temperature performance, although the total benefit in terms of distance from the line for unmodified binders is approximately the same in each case. Two binders may have the same co-ordinates on the SHRP grading chart but have been formulated in different ways. Although from Figure 5 it appears that simply increasing the polymer level gives a proportional improvement in performance, it should be remembered that these data are for a single combination of bitumen and polymer type. There are many well recognised issues affecting the characteristics of polymer modified bitumens, including polymer-bitumen compatibility and interactions, and the process of manufacture. It is therefore not possible to specify PMBs in terms of simple polymer-bitumen recipes.

Grading charts as shown in figures 4 and 5 provide a means of product selection. For example, if enhanced low temperature performance (or resistance to fatigue) is a priority, but high temperature performance equivalent to a 50 pen binder is sufficient, find the 50 pen area on the line for unmodified binders (for example 40/50) and read down. A product in the PG 70-28 grade would be expected to give similar rut resistance, but enhanced low temperature performance. Similarly, if high temperature performance is important and low temperature performance equivalent to a 40/50 grade binder is acceptable, read across from the same point towards the right. A binder graded PG 76-22 may be appropriate for this application.

Predicting SHRP grades

It has already been shown that from these data, good quality, unmodified binders plotted in terms of SHRP critical temperatures satisfy a linear relationship (equation 1). It is useful to determine whether there is a relationship between SHRP grades and more traditional measures for unmodified bitumens. This part of the study included data from the BP study, from (5) and from an additional reference (6). Data are from three different studies, by three different laboratories, but all measurements have been made such that points to plot on a Grading Chart can be extracted. Figure 6 shows data from all studies plotted on the Chart.

Figure 6 grading chart for unmodified binders from 3 independent studies

Although, as might be expected, there is more scatter in the data, there is still a good straight line relationship for the 22 binders from different crude oils and production routes. The fitted line is very similar to that fitted to the BP data only in Figure 3 and the correlation coefficient is still high $R2 = 0.92$.

To determine how the SHRP grades relate back to more traditional measures, Figure 7 shows the high temperature critical value as a function of the softening point for all the binders in Figure 6.

From these data there appears to be a very good linear relationship with a correlation coefficient $R2 = 0.98$ and described by the following equation:

- SHRP high temp critical value = $1.17 * SPt + 8.7$

Using this in combination with the equation from Figure 6, enables the complete SHRP grade for the binder to be predicted, since substitution gives:

- SHRP Low Temp Critical Value = $0.59 * SPt - 55.7$

A similar relationship is obtained between the low temperature critical value and softening point if plotted directly (not shown). The correlation coefficient for this relationship is not quite as good as that for the high temperature criterion, but is still $R2 = 0.93$.

Figure 7 predicting the SHRP high temperature critical value (unmodified binders)

Whilst a relationship between the low temperature grade and softening point clearly exists, it would be more logical for this to relate to a traditional low temperature measurement i.e. Fraass temperature. Figure 8 shows this plot for a limited number of binders for which Fraass data were reported. There is a fair degree of scatter for this relationship, but this would probably improve with a larger number of binders. There is still quite a good correlation with the following equation:

- SHRP low temp critical value = 0.62*fraass - 17.3

Figure 8 predicting the SHRP low temperature critical value (unmodified binders)

These relationships are only valid for the unmodified, paving grade bitumens included in this study. Further data would be required to validate the model for more bitumens. For example, this prediction would not necessarily be expected to hold for waxy bitumens, whose softening points are controlled by the nature of the wax.

Conclusions

Unmodified, paving grade bitumens and a range of speciality products including PMBs have been classified according to the SHRP Binder Grading System. SHRP grades were determined and it was found that the fatigue criterion did not influence the final SHRP classification for any of these binders. A high temperature critical value determined from parameters to control rutting and a low temperature critical value determined from parameters to control brittle fracture, enabled all products to be plotted on a Grading Chart based on the SHRP performance grades. From this Grading Chart it was found that:

- Good quality, paving grade bitumens appear to fall on a single line, regardless of crude source and production route. As a consequence, only certain SHRP grades can be met by unmodified binders. In order to meet higher performance grades it is necessary to use PMBs or other speciality products.
- Plotting the high temperature critical value versus softening point (unmodified bitumens) confirmed a linear relationship for this data set and data from two external sources (R2 = 0.98). This equation, together with that relating high and low temperature critical values suggests that the full SHRP grade for unmodified binders can be predicted from the softening point for bitumens discussed in this study. Fraass point also appears to predict the low temperature grade for a limited number of binders.
- PMBs and other speciality products are displaced from the line for unmodified binders. The degree of displacement gives an indication of the performance benefit which the binder provides in terms of either better resistance to permanent deformation or better resistance to brittle fracture or both. The performance benefits of the speciality binders are maintained after ageing in both the RTFOT and the PAV.
- For PMBs the performance benefit depends on both the type and concentration of polymer and the interactions between the polymer and specific base bitumen used.
- The same end performance in terms of the SHRP grade can be achieved by using different combinations of base bitumens and methods of modification.

Further work is clearly necessary to validate field performance with respect to SHRP grades. However, if SHRP specifications for binders were to become accepted more widely in the future, Grading Charts of the type developed in this work may provide a useful way of selecting a product to meet specific performance requirements in dense mixes.

References

1. Asphalt Institute Superpave Series No 1 (SP-1). Performance Graded Asphalt Binder Specification and Testing.

2. CLAXTON M J, LESAGE J, PLANQUE L, GREEN P G (1996). The use of binder rheological properties to predict the performance of asphalt mixes. Australian Road Research Board Conference, 1996.

3. CLAXTON M J, LESAGE J, MIGLIORI F, SANTAGATA E (1995). Bending Beam Rheometer: comparison of inter-laboratory results for a variety of binders. Revue Générale des Routes et des

Aerodromes, No 735 Décembre 1995.

4. CLAXTON M J, SANTAGATA E and ANDERSON D (1996). The use of the bending beam rheometer data and direct tension tester data for the prediction of the low-temperature properties of bituminous mixtures. Eurasphalt & Eurobitume Conference, Strasbourg 1996.

5. PLANCHE J-P, CHAVEROT P, LESUEUR D, HINES M L and KING G N (1996). Evaluation of modified bitumens according to SHRP binder specifications. Revue Générale des Routes et des Aerodromes, No 739 April 1996.

6. BRÛLÉ B, LARGEAUD S and MAZÉ M (1998). Polymer bitumen performance evaluation. New results and tangible proposals. Revue Générale des Routes et des Aerodromes, No 761 April 1998.